Conductivity and Thickness of DNAs

A.Yu. Kasumov[1,2*], D.V. Klinov[3]
[1]*Laboratoire de Physique des Solides, Associé au CNRS, Bât 510, Université Paris–Sud, 91405, Orsay, France.* [2]*Institute of Microelectronics Technology and High Purity Materials, Russian Academy of Sciences, Chernogolovka 142432 Moscow Region, Russia.* [3]*Shemyakin-Ovchinnikov Institute of Bioorganic Chemistry, Russian Academy of Sciences, Miklukho-Maklaya 16/10, Moscow 117871, Russia.*

Debates about conductivity of DNAs have been recently renewed due to contradictory results of direct measurements by use of electrical contacts to molecules. In several works it was discovered that double-stranded (ds)DNAs are conductors: metals or semiconductors [1-6]. However in other works [7] the absence of DNAs conductivity has been observed even for the molecules with ordered base pairs structure. Here we show that the absence of conductivity is caused by a very large compression deformation of DNAs. Thickness of such compressed DNAs is 2-4 times less than the diameter (about 2nm) of native Watson-Crick B-DNA.

$\lambda-$DNA molecules were deposited (from the same buffer solution as in [4]) on mica substrates partially covered by a Pt film with thickness of 3 nm. Using an AFM microscope operating both in standard and spreading resistance (SRM) modes it was possible to measure simultaneously the height and conductivity of the same molecules, crossing the edge of the Pt film.

In the absence of any treatment of the mica+Pt substrate we observed the DNAs with typical height about 1 nm and no contrast in the SRM mode indicating insulating molecules in agreement with previous observations (Fig. 1a,b). On the other hand, very different results are obtained if prior to deposition of molecules, a thin (about 0.5 nm) layer of island polymer film is sputtered on the surface of both Pt and mica by glow discharge of pentylamine vapor, as it was done in our previous experiments [4]. The thickness of observed DNA molecules was about 2 nm and they were clearly visible in SRM (Fig.1c,d). We interpret this native thickness the following way: the deposition of the polymer film decreases hydrofilicity of mica and thus its interaction with DNAs. Average thickness of DNA molecules on the substrates treated by pentylamine is 2.4 ± 0.5 nm for 64 measurements on different molecules; for DNAs on the clean substrate this value is 1.1 ± 0.2 nm for 57 measurements.

Careful studies in AFM have shown that hugely reduced thickness of DNAs on the clean mica and silicon substrates is real, but not an artifact of microscopy [8]. We additionally checked it by transmission electron microscopy replica method without use of AFM. DNAs on the clean surface have the same contrast as mica, and so they are insulators. On the Pt surface some of DNAs are seen in negative contrast (Fig.1b). Such a contrast was observed by STM and explained by insulating behavior of DNAs previously [9]. Contrariwise DNAs on the mica covered by polymer film are visible by SRM in positive contrast (Fig 1d,f). Thus they are conductors.

We believe the conductivity of DNAs comes from the native, periodic structure of the molecules. It is well known that the mechanical stretching deformation can lead to denaturation of DNAs [10]. Likewise, compressing deformation may be able to destroy the periodic structure of DNAs. Compressed DNA with thickness 2 - 4 times less than B-DNA represent two independent, chaotically intersecting strands. Single-stranded DNAs definitely are insulators [1].

Brief review of works [1-6] shows dsDNAs are conductors if they have native thickness about 2nm (in this case we can call it "diameter"). For suspended DNAs [2,3,5] and DNA films [1] there is no interaction with a surface, and the thickness should be close to native. For thick ropes of DNAs [6] the interaction is weak for internal DNAs inside a rope. Conductivity of native DNAs of course will depend on many factors, such as the contacts to the electrodes [11]. DNA will behave like a metal if the contacts are ohmic and the distance between them is less than a screening length of the molecule. Poor screening is a well known property of 1D systems [4]. It seems to be true for DNAs between Re/C contacts (Fig.1e) with resistance about 100 kOhms per molecule. Different types of kinks and bendings can also decrease conductivity of DNAs. Straight DNAs (Fig.1e,f) are more conductive than curved ones (Fig.1d). From the above results we conclude that dsDNA molecules can be conductors, and one can use them in molecular electronics.

We acknowledge fruitful discussions with H.Bouchiat, V.Croquette and D.Bensimon. A.K. thanks the Russian Foundation for Basic Research and Solid State Nanostructures for financial support and thanks CNRS for a visitor's position.

*Present address: RIKEN, Wako, Saitama, 351-0198 Japan. E-mail: kasumov@postman.riken.go.jp. To whom correspondence should be addressed.

[1] Y.Okahata et al. Supramol.Sci. 5,317 (1998).
[2] H.W. Fink, C.Shoenenberger, Nature 398, 407 (1999).
[3] D.Porath et al. Nature 403, 635 (2000).
[4] A.Yu.Kasumov et al. Science 291, 280 (2001).
[5] A.Rakitin et al. Phys.Rev.Lett. 86, 3670 (2001).
[6] K.-H.Yoo et al. Phys.Rev.Lett. 87, 198102 (2001).
[7] J.Storm et al. Appl.Phys.Lett. 79, 3881 (2001), and references therein.
[8] T.Muir et al. J.Vac.Sci.Technol. A16(2), 1172 (1998)
[9] R.Guckenberger et al. Science 266, 1538 (1994).
[10] P.Cluzel et al. Science 271, 792 (1996).
[11] K.W.Hipps. Science 294, 536 (2001).

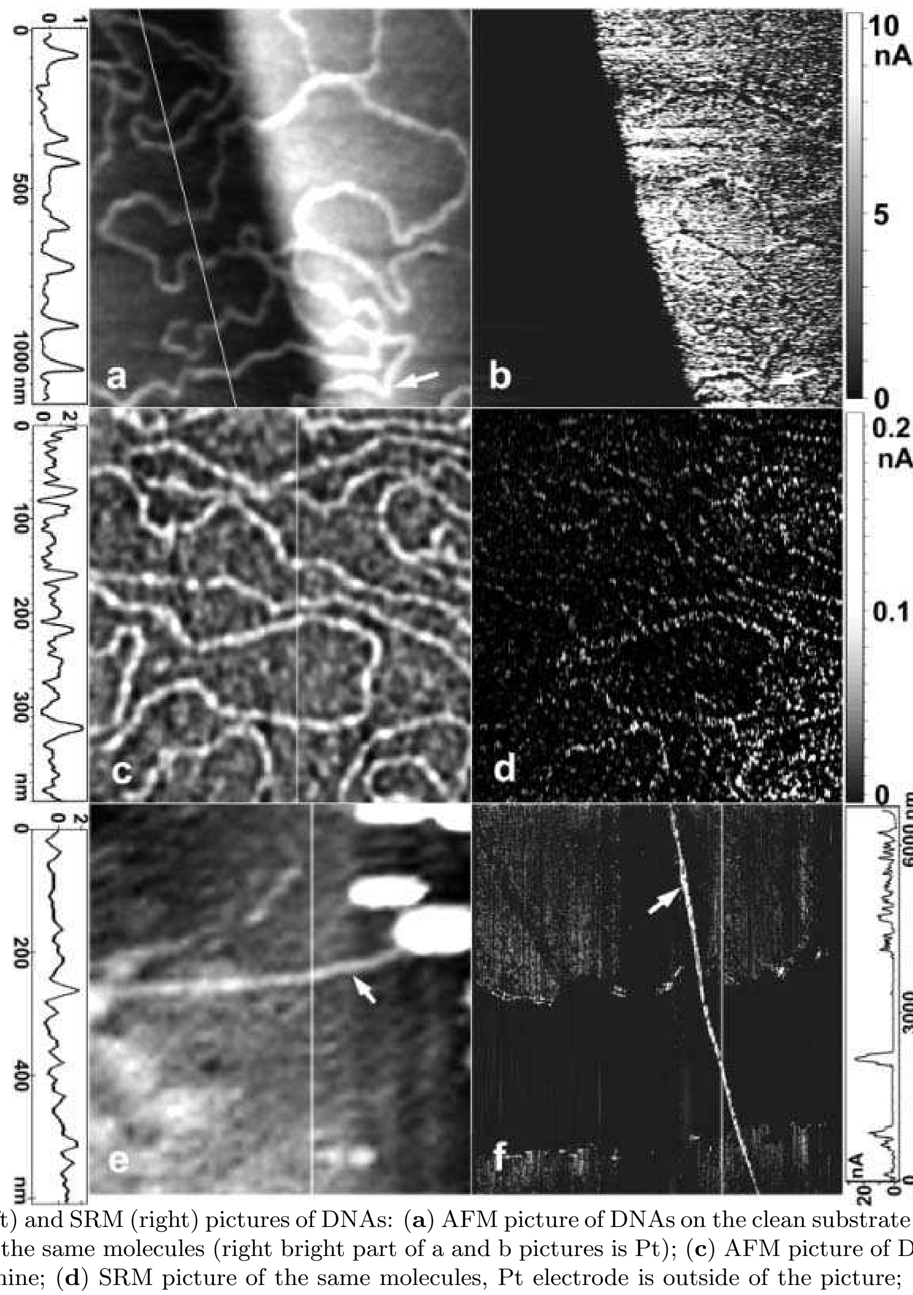

FIG. 1. AFM (left) and SRM (right) pictures of DNAs: (**a**) AFM picture of DNAs on the clean substrate without pentylamine; (**b**) SRM picture of the same molecules (right bright part of a and b pictures is Pt); (**c**) AFM picture of DNAs on the substrate treated by pentylamine; (**d**) SRM picture of the same molecules, Pt electrode is outside of the picture; (**e**) AFM picture of a DNA combed (as in [4]) across the slit between Re/C electrodes on mica; (**f**) SRM picture of a rope of DNAs combed (as in [4]) across the slit between Pt electrodes on mica. Some of DNAs are shown by arrows. From the left and right sides of the picture there are profiles of DNAs (height in nm) and current scales of SRM pictures (voltage was up to 0.23 V) respectively.